Amendments to the Specification

On page 1 of the specification, under the heading "Cross-reference to related applications", please amend the paragraph as follows:

~~Not Applicable.~~ This application is a divisional application of U.S. Patent Application No. 09/927,067, which was filed August 9, 2001.

Please make the following amendments to correct any inconsistencies in terminology. Please correct the equation numbering. In particular, please amend paragraphs 0025-0027, 0029-0030, 0032-0033, 0035, 0038-0041 and 0043 to read as follows:

[0025] Figure 2 illustrates the acoustic wave path and metal disk reverberations for a downhole acoustic wave. Shown are acoustic ~~transceiver~~transducer 200, well fluid 210 and metal disk 220. Well fluid 210 and disk 220 each has its own impedance, labeled Z_m and Z_s, respectively. Also shown is acoustic signal 250, including first reflected portion 260, disk reverberation portions 271-276 and transmitted wave portions 280, 282, 284 and 286 through the disk in the same well fluid.

[0026] To measure the reflection coefficient of the well fluid, the acoustic ~~transceiver~~transducer 200 sends out acoustic signal 250, which is preferably an ultrasonic impulse ~~250, preferably~~ with a characteristic frequency of about 500 kHz, then switches to the receive mode. The impulse frequency is preferably set at the expected resonance frequency of the disk. The ~~sound impulse~~ acoustic signal 250 travels through the well fluid 210 and strikes the disk 220. The largest portion of the energy of the impulse is reflected back to the transducer as reflected ~~wave~~portion 260 while a small amount of signal enters the disk as wave 280. When the well fluid 210 is water, the reflected wave form has an amplitude of about 93% of the initial impulse. The portion of the signal that entered the disk is reflected back and forth between the disk/fluid interface and the disk/tool interface, as illustrated by wave reverberations 271-276. At each reflection some energy is transmitted through the interface, dependent on the acoustic impedance contrast, and is either directed back toward the transducer or out into the tool. The signal inside the disk is quickly dissipated in this manner at a rate directly dependent on the acoustic impedance of the material outside the disk according to the equation:

$$R_1 = (Z_1 - Z_2) / (Z_1 + Z_2) \qquad (1)$$

where R_l is the reflection coefficient, and Z_1 and Z_2 are the impedances of the materials at the interface in question. In a preferred embodiment, the thickness of the metal disk is set to one half of the resonant wavelength of the transducer signal.

[0027] The acoustic ~~transceiver~~transducer 200, now acting as a receiver or transducer, sees a waveform consisting of a loud initial reflection followed by an exponentially decaying reverberation signal. Figure 3 illustrates the measured acoustic waveform received at the ~~transceiver~~transducer 200. If time t=0 is the time of generation of the acoustic wave at the acoustic transmitter, then the time T_{tran} represents the transit time (the time for the travel of this acoustic wave to the disk and back to the transceiver). Since the distance is fixed, the transit time T_{tran} provides an indication of the acoustic velocity of the fluid. Also shown in Figure 3 are the Time Offset, T_{off}, and the Resonance Window, T_{win}, both of whose significance is explained below.

[0029] Figure 5 illustrates a device built in accord with a preferred embodiment. Shown in Figure 5A is acoustic ~~transceiver~~ transducer 200, analog-to-digital converter 500, a processor 510 for recording start time and gain, waveform compression chip 520, and multiplexer 530. Waveform compression chip 520 could alternately be part of a processor. Also shown are downhole transmitter 540 connected to multiplexer 530 and telemetry cable 545. Referring now to Figure 5B, at the surface are located uphole receiver 550, demultiplexer 560, transmission line 564 carrying tool information to processor 590 for a data log 595, transmission line 570 carrying gain and start time information to uphole processor 590, and waveform decompression chip 580. Attached to decompression chip 580 is processor 590. Processor 590 generates data suitable for a log 595.

[0030] Referring now to both Figs. 5A and 5B, acoustic ~~transceiver~~transducer 200 collects data of metal disk reflection and reverberation. This acoustic waveform is digitized by analog-to-digital converter 500 and sent to processor 510, which detects the first reflection from the digitized signal. Processor 510 then computes the relevant start time and transit time. Because the total waveform data may be greater than the bandwidth capacity of transmission line 545, digital compression 520 is preferably performed. Suitable compressions include wavelet and ADPCM (Adaptive Differential Pulse Code Modulation) techniques, which work well for smoothly varying data. The compressed waveform from digital compression chip 520 is then multiplexed 530 with the other tool information. Downhole transmitter 540 sends this multiplexed data to the surface. Sending the data to the surface allows processing by faster, more sophisticated machinery.

[0032] Figure 6 illustrates a general method for the present invention. In block 600, an observed waveform is provided uphole for processing. In some embodiments, it may be desirable to stack waveforms (block 610). The waveform's transit time (T_{tran}) is obtained in block 620, as well as the time windows T_{off} and T_{win}. The definition of transit time was explained above with reference to Figure 3 and may be easily measured by a first reflection detector portion of processor 510. T_{off} and T_{win} are then selected to obtain a time window T_{win} that contains reliable reverberation information. T_{off}, measured from the time of receipt for the initial reflection, is a time window that encompasses the initial reflection. As such, its duration is dependent upon the duration of the acoustic impulse transmitted by acoustic ~~transceiver~~transducer 200 and the nature of the drilling fluid. T_{off} also preferably accounts for error introduced because of the real-world shortcomings of the acoustic transducer (transducer "ringing"), and thus T_{off} may be slightly longer than if chosen theoretically. Nonetheless, T_{off} is about 15 microseconds. T_{win} is juxtaposed with T_{off} and is a time window of interest because T_{win} contains reverberation information uncontaminated by the first reflection. The duration of T_{win} should be brief enough so that noise and reverberations occurring in the tool 10 do not make unreliable the received disk reverberation waveforms. Nonetheless, so that a reliable wave train containing sufficient data is obtained, T_{win} preferably includes at least four reverberations. Thus, T_{win} is about 12.8 microseconds.

[0033] The tool calibration may be obtained as follows. First, the reflection waveform defined by T_{off} is transformed to the frequency domain by use of DFT (Discrete Fourier Transform). Referring back to Figure 6, proper modeling applied to the first reflection ~~signal~~portion 260, as defined by T_{off}, gives a theoretical prediction of what the reverberation waveform contained in T_{win} should look like. To accomplish this, in block 630 the first reflection signal is transformed by Fast Fourier Transform (FFT) into its frequency domain equivalent. This yields $S(\omega)$. Because the modeling is done in the frequency domain, amplitude and phase errors are eliminated. This error elimination simplifies mathematical processing (and hence faster processing is obtained).

[0035] In block 640, a theoretical prediction of the reverberation waves is obtained by multiplying (convolution in time domain) the frequency-domain first reflection signal $S(\omega)$ with a frequency-domain theoretical response equation $R(\omega)$ to obtain a frequency domain version $X(\omega)$ of the

reverberation signal x(t). Assuming a flat metal disk, the theoretical frequency domain response may be modeled by the following:

$$R(\omega)=\frac{Z_m-Z_s}{Z_m+Z_s}+\frac{\frac{4Z_mZ_s(Z_s-Z_m)}{(Z_m+Z_s)^3}}{1-\left(\frac{Z_s-Z_m}{Z_m+Z_s}\right)^2 e^{-i2\omega\frac{C_T}{V_s}}}e^{-i2\omega\frac{C_T}{V_s}} \qquad \cancel{(4)}\underline{(2)}$$

Where

$R(\omega)$	= the reflection coefficient for angular frequency ω
Z_m, Z_s,	= impedances for mud and metal disk, respectively
V_s	= the speed of sound in the metal disk<u>, and</u>
C_T	= the thickness of the metal disk<u>.</u>

[0038] Two embodiments for relating theoretical and measured responses in block 640 include 1) a curve fitting method and 2) a non-linear waveform inversion method. Both methods calculate theoretical waveform response based on ~~Equation 4~~ <u>Equation 2</u>. However, the curve fitting method uses fewer theoretical modeling steps than the inversion method.

[0039] Figure 7A illustrates the curve fitting method, where a measurement equation is determined. As an initial matter, for a reverberation window of interest, T_{win}, the natural log of the sum of the reverberation waveform amplitude (S_w) varies linearly with well fluid impedance. That is, a linear relationship between well fluid impedance and S_w may be expressed as:

$$Z_m = A + B \ln (S_w) \qquad \cancel{(6)}\underline{(3)}$$

where S_w is the sum of the reverberation waveform amplitudes and has the form:

$$S_w = \sum_t |x(t)| \qquad \cancel{(7)}\underline{(4)}$$

the lower case x(t) being the amplitude at any given point in the reverberation waveform contained in T_{win}.

[0040] For the curve-fitting method, block 640 includes blocks 700-760. In block 700, an initial theoretical fluid impedance Z_m is chosen. In block 710, the theoretical response $R(\omega)$ is calculated in accordance with ~~Equation 4~~ <u>Equation 2</u>. In block 720, the first reflection is convolved with the theoretical response obtained in block 710. In block 730, the Inverse Fast Fourier Transform (IFFT) is performed to obtain a theoretical reverberation waveform. Next, the summed amplitudes of the theoretical reverberation waveform S_w is determined in block 740. In block 750, the

theoretical response $R(\omega)$ and reverberation waveform amplitude sum S_w are stored. In block 760, it is decided whether or not additional data is needed. If additional data is necessary, another theoretical fluid impedance Z_m may be chosen in block 700. To determine the coefficients in this linear relationship, steps 700-760 are repeated at least twice for different assumed fluid impedances Z_m. Each time, the resulting sum S_w is calculated. From these multiple points, (S_w, Z_m), the coefficients A, B, can be determined using the least squares curve fitting in block 770. With the relationship, the measured impedance Z_m can be determined from the observed S_w using ~~Equation 7~~ Equation 4 in block 780.

[0041] Lastly, in block 650 (Figure 6), S_w is substituted into ~~Equation 6~~ Equation 3, and well fluid impedance Z_m is determined. The acoustic velocity of the fluid may also be calculated in block 650. Because the separation between the transducer and disk is known, the velocity is calculable from the measured transit time T_{tran}. From the impedance (ρ) and velocity (v), the fluid density (Z_m) can be calculated due to the relationship: $Z_m = \rho v$.

[0043] In the non-linear waveform inversion embodiment shown in Figure 7B, fluid properties such as velocity, density, and attenuation are initially estimated in block 800. In block 810, the theoretical response $R(\omega)$ is calculated in accordance with ~~Equation 4~~ Equation 2. In block 820, the first reflection is convolved with the theoretical response obtained in block 710. In block 830, the Inverse Fast Fourier Transform (IFFT) is performed to obtain an estimated reverberation waveform. In block 840, the error between the estimated and measured waveforms is determined. The error is calculated according to ~~Equation 8~~ Equation 5.

$$\text{Error} = \sum \left| (observed - theoretical)^2 \right| \qquad \cancel{(8)}(5)$$